HERBICIDE CARRY-OVER

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HERBICIDE CARRY-OVER

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Herbicide carry-over

Herbicides enter the soil when they are applied directly to it or onto foliage and from residues of a treated crop. In soil some herbicides persist longer than others under local weather and soil conditions (Table 1). Persistence of a particular herbicide may be advantageous when extended weed control is required. However, under certain weather and soil conditions the herbicide may persist too long and leave residual toxicity or carry-over which can damage succeeding crops (e.g., canola crop damage caused by Glean carry-over. Fig. 1). In other words, persistence of a herbicide becomes a problem when its active ingredient remains in the soil in sufficient concentration to injure a sensitive or a marginally tolerant crop the following year (e.g., damage to barley plants from Treflan residues in soil. Fig. 2).

I. Evans

Figure 1. Canola crop damage caused by Glean carry-over.

D. Lobay

Figure 2. Damage to barley plants from Treflan residues in soil.

TABLE 1. HERBICIDE PERSISTENCE IN SOIL UNDER GOOD GROWING CONDITIONS†

	Common name		Trade name(s)
*	acrolein	One month or less	Magnacide-H
	amitrole		Amitrole-T
	barban		Carbyne 2EC
*	dalapon		Dowpon, Radapon
	2,4-D		Several products
	2,4-DB		Embutox 625, 2,4-D Butyric 400, Cobutox 400
**	diquat		Reglone
	glyphosate		Roundup
*	ioxynil		Actrilawn, Totril, Certrol
	MCPA		Several products
*	MCPB		Can-Trol, Thistrol
**	paraquat		Gramoxone, Sweep
	propanil		Stampede 360
		One to three months	
*	butylate		Sutan
	chloramben		Amiben
*	cycloate		Ro-Neet
*	desmedipham		Betanex
*	diphenamid		Enide
	EPTC		Eptam, Eradicane 8-E
	mecoprop		Mecoturf, Iso-cornox 64
	TCA		Sodium TCA
	triallate		Avadex BW
*	2,4,5-T		Several products
		Three to twelve months††	
*	alachlor		Lasso
	atrazine		Aatrex, Primatol, Atrazine F
	bromoxynil		Torch DS, Pardner
	cyanazine		Bladex Liquid, Bladex 80W, Bladex TTC
	dicamba		Banvel, DyCleer
	dichlobenil		Casoron
	difenzoquat		Avenge 200-C
	diuron		Karmex
*	ethalfluralin		Sonalan
	linuron		Afolan F, Lorox L
	metobromuron		Patoran
	metolachlor		Dual
	metribuzin		Sencor, Lexone
	simazine		Princep Nine-T, Simmaprim
	trifluralin		Treflan, Heritage, Rival, Triflurex
		Over twelve months†††	
*	borate		Monobor-chlorate, Ureabor
	bromacil		Hyvar-X
	chlorsulfuron		Glean
	hexazinone		Velpar
	picloram		Tordon
	tebuthiuron		Spike, Herbec 20P
	terbacil		Sinbar
*	2,3,6-TBA		Benzac, Trysben

* Herbicide not listed in "Guide to Crop Protection in Alberta — 1987".

** Although diquat and paraquat molecules may remain unchanged in soils, they are adsorbed so tightly that they become biologically inactive.

† These are approximate values generated in moist fertile soil and summer temperatures in a temperate climate (After Klingman, G.C. and F.M. Ashton. 1982).

†† At high rates of application, some of these chemicals may persist at active levels for more than 12 months.

††† At lower rates of application, some of these chemicals may persist at active levels for less than 12 months.

Can we predict carry-over of a herbicide?

Herbicide carry-over is the amount of active ingredient present in the soil after all breakdown and physical loss has occurred throughout the season. Loss of a herbicide from the soil depends mainly on local weather conditions and soil characteristics. However, weather conditions such as rainfall and temperature vary from year to year making it difficult to predict accurately and confidently the amount of carry-over from one year to the next. For instance, a dry year generally results in higher than normal carry-over from Avadex BW and Treflan applied at recommended rates. This carry-over can cause injury to cereals, especially wheat, the following year. Limited experience in the application of herbicides and the introduction of an increasing number of new products also add to the difficulty in predicting herbicide carry-over.

Information and experience are lacking in handling unexpected problems arising from carry-over of a particular herbicide. As an example, in Manitoba, soil moisture reserves at seeding time in 1977 were very low and the seedbed was dry. Growers planted their cereals deeper than recommended. Because of the previous dry year, Treflan residues in 1977 were higher than normal. Deep seeding, coupled with higher than normal residues, resulted in an unusual degree of crop injury, especially to wheat. Under more normal conditions neither deep seeding nor carry-over would have caused damage to these cereal crops.

A good understanding of the characteristics of herbicides and the factors affecting herbicide persistence in soil is essential in predicting carry-over of a herbicide. Such knowledge will also be useful in preventing herbicide carry-over and in managing soils which may contain residues to minimize crop injury or loss.

Why is a herbicide carried over?

When a herbicide enters the soil it is immediately subjected to a variety of processes. These processes are physical, chemical and biological in nature and occur in soils all the time. They result in either physical removal of the herbicide or its breakdown into nontoxic compounds (Fig. 3). The efficiency of these processes under certain environmental conditions determines the net carry-over of a particular herbicide from one year to the next. For example, an application of Glean will result in more carry-over in southern Alberta than in northern Alberta — mainly because of different soil characteristics, such as pH and organic matter content, and to weather conditions like rainfall and temperature.

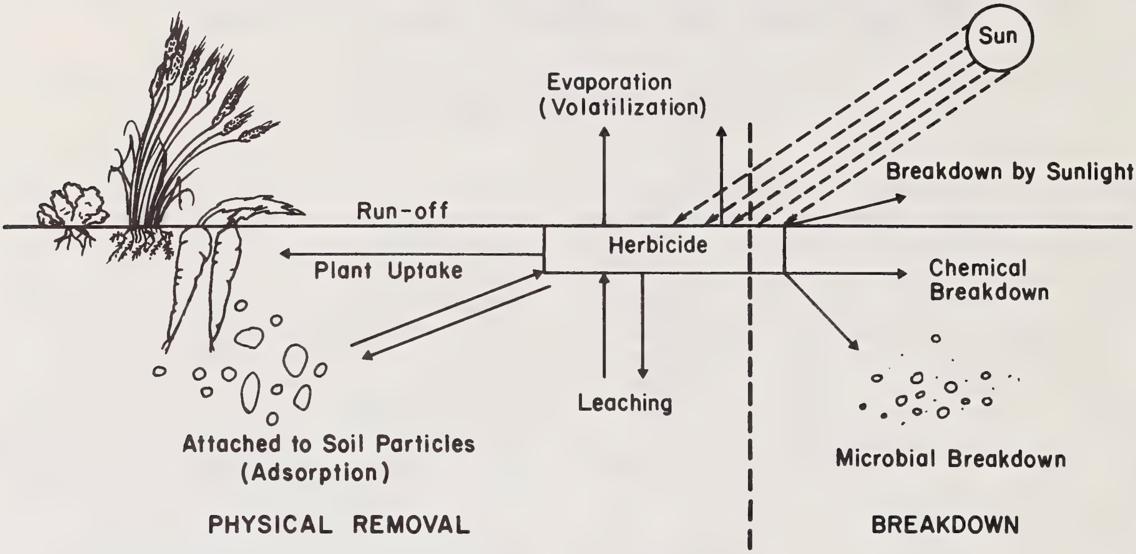

Figure 3. Herbicide removal and breakdown in soil.
(After Roberts, H.A. 1982).

What factors affect herbicide carry-over?

Persistence of a herbicide in soil — thus its carry-over into the next year — depends upon several factors related to the herbicide itself, and to soil and climatic conditions. In addition, crop management practices influence the potential for herbicide carry-over.

HERBICIDE-RELATED FACTORS

The type of herbicide used, its formulation, and its rate, time and method of application play an important role in its carry-over to the following year. Therefore, an understanding of herbicide characteristics and their correct application will certainly assist in minimizing carry-over and potential for crop injury.

Properties of herbicides

Herbicides differ in their physical and chemical properties, such as water solubility, volatility (evaporation) and susceptibility to breakdown by sunlight and biological or chemical processes. These characteristics determine the relative persistence of a given herbicide in soil. Persistent herbicides usually have one or more of the following properties:

- Low water solubility (e.g. Aatrex)
- Moderate degree of adsorption (e.g. Treflan)
- Low volatility (e.g. Princep)
- Low susceptibility to decomposition by light (e.g. Glean)
- Low susceptibility to chemical degradation (e.g. Sencor)
- Low susceptibility to microbial decomposition (e.g. Tordon)

Water solubility — Herbicides differ in their water solubility (Table 2). Those that are soluble or dissolve easily in soil water are easily leached, that is, these herbicides move with the soil water. Leaching, which may occur downward, upward or sideways in soil, results in physical removal of the herbicide from the treated area. It also enhances herbicide dissipation by other means (adsorption on clay in soil, loss to the atmosphere by evaporation and breakdown by sunlight) and reduces the potential for herbicide carry-over. On the other hand, herbicides that are less soluble in water do not move very far from the treated area thus resisting physical removal and/or dissipation by other processes. These herbicides are carried over to the next year.

Adsorption — Adsorption is the binding of a herbicide to the surface of soil particles. All herbicides are adsorbed to some extent. The structural (molecular) characteristics of a herbicide determine the nature and extent of its binding in a given soil. Once adsorbed it may not be available for uptake by plants or dissipation by other processes. The strength and extent of binding and the ease with which a certain herbicide is replaced or released will affect the persistence and carry-over of the herbicide in soil.

Herbicides that ionize in water solution, i.e. ionic herbicides, have an adsorptive nature different from nonionic herbicides. Herbicides with positively charged ions (cationic herbicides), such as Gramoxone or Reglone, are more strongly adsorbed than those with negatively charged ions (anionic herbicides) in soil solution. Among anionic herbicides, the basic herbicides such as Aatrex and Sencor are more strongly adsorbed than acidic herbicides such as 2,4-D, Banvel and Tordon.

Volatility — Volatility or evaporation is the tendency of a chemical to pass from the solid or liquid state to the gaseous state. All herbicides are volatile to some extent and their volatility depends in part on their vapor pressure. Herbicides with low vapor pressure are less volatile. For example, Princep with low vapor pressure is nearly nonvolatile, compared with Treflan, Avadex BW or Eptam with relatively high vapor pressures (Table 3). More volatile herbicides are lost faster from the soil surface than less volatile ones which can be carried over into the next year.

Decomposition by sunlight — Most herbicides are relatively resistant to decomposition by sunlight. This property contributes to their relative persistence in soil. A few, including Treflan, when exposed to sunlight, are decomposed by photochemical reactions. Under field conditions this may be an important mechanism for the inactivation of herbicides on the soil surface or in water. However, it plays a minor role in the breakdown once the herbicide is soil-incorporated.

Chemical degradation — Herbicides react with chemicals present in soil, generally resulting in a change in the nature of molecules responsible for herbicidal activity. Chemical degradation may involve one or more reactions, including hydrolysis and oxidation-reduction. For example, Dowpon will slowly hydrolyze in the presence of water, becoming ineffective as a herbicide, with no carry-over. Herbicides which are less sensitive to chemical degradation have a relatively higher potential for carry-over.

Microbial decomposition — Herbicides present in soil are taken up and metabolized by soil microorganisms such as bacteria, algae and fungi. This is one of the most important mechanisms by which herbicides are decomposed in the soil, thus reducing the carry-over potential. The chemical structure of a herbicide determines its susceptibility to microbial decomposition and thus its relative carry-over potential. For example, phenoxy herbicides such as 2,4-D and MCPA are susceptible to microbial decomposition while Tordon, Aatrex and Treflan are relatively resistant to microbial decomposition (Table 4) and exhibit relatively higher potential for carry-over.

Formulation

The type of herbicide formulation gives an indication of its carry-over potential. For instance, the granular formulations of Avadex BW and Treflan have higher carry-over potential than their emulsifiable concentrate formulations. The difference in persistence is mainly caused by the greater loss of herbicide from the instantly exposed volatile emulsifiable form.

Rate of application

The amount of a herbicide applied in any one season is an important factor in whether or not herbicide carry-over will be a problem the following crop year. For example, under similar soil and climatic conditions, Treflan applied at the higher recommended rate can result in a little more residue carry-over the following year than if applied at the lower recommended rate.

TABLE 2. WATER SOLUBILITY OF SELECTED HERBICIDES*

Herbicide		Water solubility	Temperature
Common name	Trade name(s)	ppm	°C
glyphosate	Roundup	350,000	20
amitrol	Amitrole-T	280,000	25
chlorsulfuron	Glean	28,000	25 (pH7)
chlorsulfuron	Glean	300	25 (pH5)
dicamba	Banvel	4,500	25
diclofop methyl	Hoe-Grass	3,000	22
tebuthiuron	Spike, Herbec 20P	2,300	25
metribuzin	Sencor, Lexone	1,220	20
2,4-D	Several products	900	25
bromacil	Hyvar-X	815	25
terbacil	Sinbar	710	25
benazolin	Benazolin	600	20
metolachlor	Dual	530	20
propanil	Stampede	500	20
picloram	Tordon	430	25
EPTC	Eptam	370	20
alachlor	Lasso	242	25
cyanazine	Bladex	171	25
linuron	Afolan F, Lorox L	75	25
sethoxydim	Poast	48	25
diuron	Karmex	42	25
atrazine	Aatrex, Primatol	33	27
triallate	Avadex BW	4	25
fluazifop-butyl	Fusilade	2	20
ethalfluralin	Sonalan	<1	25
MCPA	Several products	<1	25
trifluralin	Treflan, Heritage, Rival	<1	25

*Data from Herbicide Handbook of the Weed Science Society of America, Fifth Edition, 1983.

TABLE 3. VAPOR PRESSURE OF SELECTED HERBICIDES*

Herbicide		Vapor pressure	Temperature
Common name	Trade name(s)	mm Hg	°C
EPTC	Eptam	3.4×10^{-2}	25
butylate	Sutan	1.3×10^{-2}	25
dichlobenil	Casoron	5.5×10^{-4}	20
triallate	Avadex BW	1.2×10^{-4}	25
trifluralin	Treflan, Rival	1.1×10^{-4}	25
ethalfluralin	Sonalan	8.2×10^{-5}	25
fluazifop-butyl	Fusilade	5.5×10^{-5}	20
alachlor	Lasso	2.2×10^{-5}	25
clopyralid	Lontrel	1.3×10^{-5}	25
metribuzin	Sencor, Lexone	1.0×10^{-5}	20
tebuthiuron	Spike, Herbec 20P	2.0×10^{-6}	25
diclofop methyl	Hoe-Grass	0.25×10^{-6}	20
picloram	Tordon	6.16×10^{-7}	35
terbacil	Sinbar	4.8×10^{-7}	30
sethoxydim	Poast	1.6×10^{-7}	25
atrazine	Aatrex, Primatol	1.5×10^{-7}	25
simazine	Princep Nine-T, Simmaprim	6.1×10^{-9}	20
cyanazine	Bladex	1.6×10^{-9}	20

*Data from Herbicide Handbook of the Weed Science Society of America, Fifth Edition, 1983.

TABLE 4. MAJOR MODE OF DEGRADATION AND CARRY-OVER OF COMMONLY USED HERBICIDES IN PRAIRIE SOILS*

Herbicide	Application	Major mode of degradation	Carry-over to next crop year	Field leachability
Aatrex	Post-emergence Pre-emergence	Chemical	Range from 15-30%	Negligible
Avadex BW	Pre-emergence (soil incorporated)	Evaporation from treated soils	Usually about 15%	Nil
Banvel	Post-emergence	Microbial	None	Can be extensive
Benazolin	Post-emergence	Microbial	Usually less than 15%	Negligible
2-4,D	Post-emergence	Microbial	None	Slight
Eptam	Post-emergence (soil incorporated)	Evaporation from treated soils	Usually less than 15%	Slight
Glean	Post-emergence	Chemical	Over 15%	Can be extensive
Hoe-Grass	Post-emergence	Microbial	Usually less than 15%	Nil
Lasso	Post-emergence	Microbial	Usually less than 15%	Negligible
Lontrel	Post-emergence	Microbial	—	Extensive
Lorox L or Afolan F	Post-emergence Pre-emergence	Microbial	Can range from 15-30%	Negligible
Mataven	Post-emergence	Microbial	Can range from 15-30%	Nil
Sencor or Lexone	Post-emergence	Microbial	Usually less than 10%	Moderate
Torch DS	Post-emergence	Microbial	None	Negligible
Tordon	Post-emergence	By dilution	Over 30%	Extensive
Treflan	Pre-emergence (soil incorporated)	Evaporation from treated soils	Usually about 15%	Nil

* After Smith, A.E. and B.J. Hayden. 1980.

Time of application

An early application of a herbicide will increase the period during which the herbicide will be subjected to physical removal or breakdown in soil. This practice will reduce the potential for carry-over the following year. A late application, on the other hand, will increase chances of herbicide carry-over.

Method of application

Poor distribution of herbicide in the soil can cause herbicide carry-over. Poor distribution may result from improper equipment calibration or agitation, overlapping or double application, or poor incorporation. Herbicide carry-over is often most prevalent in headlands where the operator slows down to turn. Slow speed on wet soil or on hills can result in the overapplication of a herbicide, resulting in "hot spots".

Repeated use

Several studies reported no significant build-up of some herbicides in soil after repeated annual applications (Table 5). However, the use of certain herbicides for more than one year may result in an accumulation of their residues in soils to levels damaging to rotational crops. The degree of residue build-up of a herbicide depends upon weather conditions and soil characteristics. For example, even under favorable soil and weather conditions in central Alberta, cereals may suffer injury if planted in fields treated with Treflan during the previous two growing seasons. Similarly, repeated use of Glean, Avadex BW, Tordon 202C, Aatrex and other persistent herbicides will result in greater carry-over, limiting rotation options.

SOIL-RELATED FACTORS

Soils are not the same everywhere. Each soil has its own unique properties which are important in determining herbicide carry-over. Such soil characteristics include texture, organic matter, pH, temperature and moisture.

Texture

The relative percentages of sand, silt and clay in a soil determine its texture (Fig. 4). Loose-textured soils such as coarse sandy loams favor herbicide leaching and fine-textured soils such as clay loams favor adsorption of herbicides. This is because of the variable content of clay particles in the two types of soil.

Clay particles provide adsorption surfaces to bind herbicides. Soil texture, therefore, is one factor in determining the rate of application of herbicides. For example, Treflan is applied at higher rates on heavy soils than on lighter soils (Table 6). Soil texture also determines the movement of a herbicide. There is more downward leaching in soils of loose texture, such as coarse sandy loams, than in soils of fine texture, such as silt loams (Table 7). For instance, Aatrex may leach more readily in sandy loams than in silt loams. In some types of soil, Tordon is known to leach in the lower profiles and later move up with water to the surface layers, resulting in injury to sensitive crops.

Organic Matter

Organic matter, the remains of plants and animals in various stages of decomposition, is one of the most important factors influencing herbicide carry-over. This is because organic matter particles have the specific capacity to attract and hold herbicides (Table 8) and because the adsorbed herbicides are also released at specific rates. For instance, herbicides such as Treflan (Table 6) and Avadex BW (Table 9) are recommended at higher rates to achieve acceptable levels of weed control in soil with higher organic matter. This is because a part of the applied herbicides is adsorbed by organic matter particles making herbicides not available for uptake by the growing seedlings of wild oats. The adsorbed portions of these herbicides, which are released at specific rates, persist longer and can be carried over in these soils.

Soil pH

Soil pH is the degree to which a soil is acid or alkaline. It is expressed as a number on a scale ranging from 0 to 14. The middle value 7 is neutral, neither acid nor alkaline. A reading below 7 is acid, above 7 is alkaline. Herbicides are adsorbed more strongly in soils which are acid (low pH) and less so in those which are alkaline (high pH) (Table 10).

Soil pH may affect herbicide degradation directly if the stability of the herbicide is influenced by the acid or alkaline nature of the soil solution, or indirectly by its effects on microbial decomposition. Atrazine, Sencor and Glean are known to be more persistent in alkaline soils than in acid soils. Residues of these herbicides are commonly carried over in alkaline soils causing crop injury the next year.

TABLE 5. RESIDUES IN FIELD SOILS FOLLOWING REPEATED ANNUAL APPLICATIONS OF HERBICIDES*

Herbicide†	Consecutive applications and years	Rate (kg/ha)	Location	Soil**	Date(s) sampled	Soil depth (cm)	Herbicide residues (ppm)
atrazine (Aatrex)	9†† 1963-71	4.50	Harrow	SL	July 1971	0-15	0.473
atrazine (Aatrex)	20†† 1959-78	1.40-2.24	Ottawa	SL	Oct. 1978	0-15	0.102 as atrazine 0.378 as hydroxyatrazine
					May 1979	0-15	0.055 as atrazine 0.296 as hydroxyatrazine
2.4-D	35 1947-81	1.12-1.69	Indian Head	C	Oct. 1978 — 1981	0-10	<0.050
dichlobenil (Casoron)	6 1971-76	8.80	Trenton	L	1976	0-15	0.570
diuron (Karmex)	9†† 1963-71	4.50	Harrow	SL	July 1971	0-15	1.760
diuron (Karmex)	7†† 1966-72	4.50	Harrow	SL	July 1972 April 1974	0-15 0-15	3.283 0.952
diuron (Karmex)	6 1971-76	4.40	Trenton	L	1976	0-15	2.400
linuron (Lorox L)	9†† 1963-71	4.50	Harrow	SL	July 1971	0-15	1.375
paraquat (Gramoxone)	9†† 1963-71	2.24	Harrow	SL	Oct. 1971	0-15	4.120
paraquat (Gramoxone)	9†† 1963-71	6.72	Harrow	SL	Oct. 1971	0-15	5.960
picloram (Tordon)	8†† 1966-73	0.02-0.07	Scott	L	1970-1974	0-30	<0.030

TABLE 5. Continued.

Herbicide†	Consecutive applications and years	Rate (kg/ha)	Location	Soil**	Date(s) sampled	Soil depth (cm)	Herbicide residues (ppm)
picloram (Tordon)	4 1975-78	0.56	Moose Jaw	CL	1975-1978	0-7	<0.168
simazine (Princep)	9†† 1963-71	4.50	Harrow	SL	July 1971	0-15	0.473
simazine (Princep)	9†† 1963-71	4.50	Harrow	SL	Mar. 1973	0-15	0.016 as simazine 0.708 as hydroxysimazine
simazine (Princep)	7 1966-72	4.5	Harrow	SL	July 1972	0-15	1.022 as simazine, 1.864 as hydroxysimazine
					Oct. 1974	0-15	0.006 as simazine, 0.496 as hydroxysimazine
simazine (Princep)	6 1971-76	4.40	Trenton	L	1976	0-15	3.080
terbacil (Sinbar)	7†† 1966-72	4.50	Harrow	SL	July 1972 Apr. 1974	0-15 0-15	4.070 0.510
terbacil (Sinbar)	6 1971-76	4.40	Trenton	L	1976	0-15	1.470

*After Smith, A.E. 1982a.
**Soil types: C — clay, CL — clay loam, L — loam, SL — sandy loam

†Trade names in parentheses.
††Other herbicides used during this period for additional weed control.

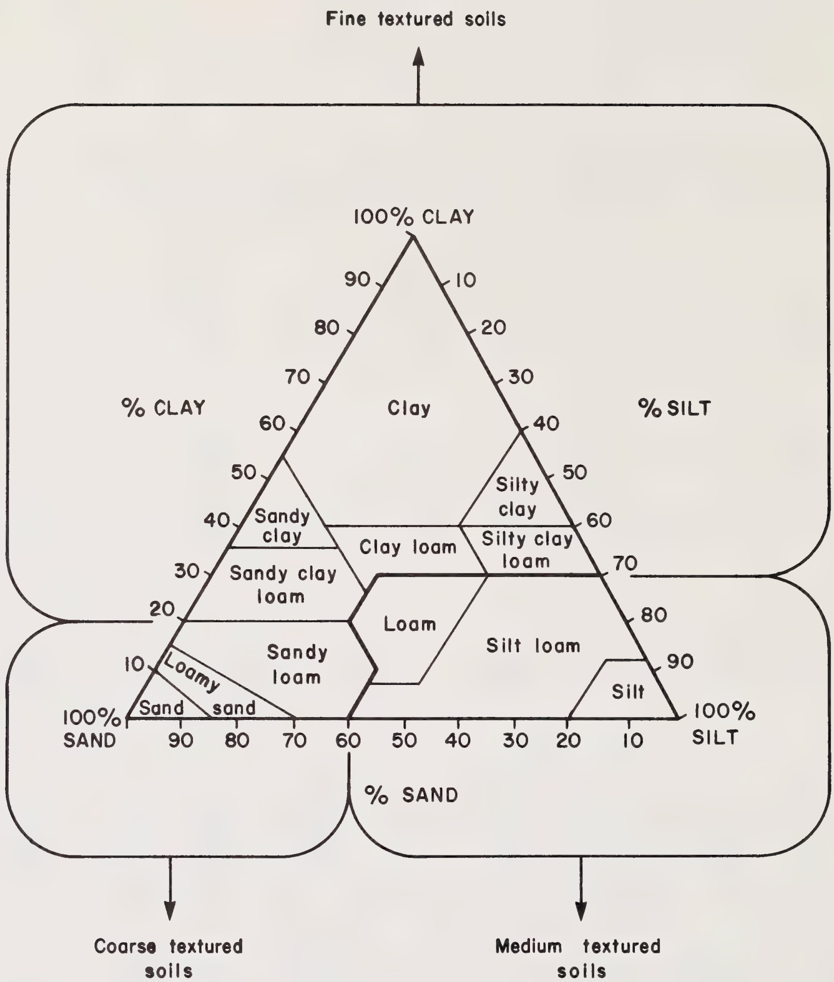

Figure 4. Soil textural classification illustrated by the standard textural triangle of sand, silt and clay fractions (Ross, M.A. and C.A. Lembi. 1985).

TABLE 6. EFFECT OF SOIL TEXTURE ON THE RATE OF TREFLAN EC REQUIRED FOR WEED CONTROL IN ALBERTA*

Time of application and crops	Recommended rate of Treflan EC per hectare** — Soil texture: Light (Sand, Sandy loam (less than 6% organic matter))	Recommended rate of Treflan EC per hectare** — Soil texture: Medium or heavy (Loam, Silt loam, Silt, Sandy clay loam (all soils with 6-15% organic matter); Silty clay loam, Clay loam, Silty clay, Clay)	Comments
Spring application Canola, sunflower, mustard, faba beans, crambe, peas (field & canning), black beans, dry beans, soybeans	2.0 L	2.75 L	Treflan can be applied immediately or up to 3 weeks before planting.
Shelterbelts American, elm, caragana, green ash, Scotch pine, Siberian elm	5.5 L	11.0 L	Apply prior to transplanting seedlings, the higher rate of application will result in better weed control and longer persistence in the soil. Wild mustard may not be controlled at these rates.
Fall application Canola, sunflower, mustard, flax, peas, faba beans, black beans, soybeans	2.75 L	3.5 L	Apply and incorporate between Sept. 1 and soil freeze-up.
Summer application Canola, flax	4.25 L	4.25 L	Apply and incorporate between June 1 and Sept. 1. Second and subsequent incorporations may be up to soil freeze-up.

*Anonymous. 1981.
**Treflan EC contains Trifluralin 400 g/L

TABLE 7. RELATIVE MOVEMENT BY LEACHING OF SELECTED HERBICIDES THROUGH 100-cm COLUMNS OF SOIL*

Herbicide		Depth herbicide leached down (cm)	
Common name	Trade name(s)	Silt loam	½ loam + ½ sand
trifluralin	Treflan, Rival	2	5
butylate	Sutan	9	17
linuron	Afolan F, Lorox L	10	19
simazine	Princep, Simmaprim	4	27
alachlor	Lasso	20	28
diuron	Karmex	21	28
EPTC	Eptam	24	42
atrazine	Aatrex, Primatol	25	48
tebuthiuron	Spike, Herbec 20P	51	81
bromacil	Hyvar – X	55	88
dicamba	Banval	91	95
chlorsulfuron	Glean	100	100
hexazinone	Velpar	100	100

*Ross, M.A. and C.A. Lembi. 1985.

TABLE 8. RELATIVE ADSORPTION OF SOME COMMON HERBICIDES BY SOIL ORGANIC MATTER*

Herbicide		Adsorptivity to soil organic matter
Common name	Trade name(s)	
dalapon	Dowpon	None
chloramben	Amiben	Weak
dicamba	Banvel	"
bentazon	Basagran	"
2,4-D	Several products	Moderate
propachlor	Ramrod, Bexton	"
metribuzin	Lexone L, Sencor	"
atrazine	Aatrex, Primatol	Strong
cyanazine	Bladex	"
simazine	Princep, Simmaprim	"
alachlor	Lasso	"
metolachlor	Dual	"
EPTC	Eptam	"
diuron	Karmex	"
linuron	Lorox L, Afolan F	Very Strong
paraquat	Gramoxone	"
butylate	Sutan	"
trifluralin	Treflan, Rival,Triflurex	"
triallate	Avadex BW	"

* After Paulson, Jr., D. 1981.

TABLE 9. EFFECT OF SOIL ORGANIC MATTER CONTENT ON THE RECOMMENDED RATE OF APPLICATION OF AVADEX BW*†

Spring application

		Organic matter in soil			
		4% or Less		Greater than 4%	
Crops	Application timing	Liquid L/ha	Granules kg/ha	Liquid L/ha	Granules kg/ha
Wheat (spring, durum)	Before seeding	3.0	11.0	3.5	14.0
	After seeding	3.5	14.0	4.2	17.0
Barley	Before or after seeding	3.5	14.0	4.2	17.0
Canola, flax, mustard, sugar beets	Before seeding	4.2	17.0	5.5	22.0
Peas (dry)	Before seeding	4.2	—	4.2	—

Fall application

	Organic matter in soil					
	Less than 2%		2-4%		Greater than 4%	
Crops	Liquid L/ha	Granules kg/ha	Liquid L/ha	Granules kg/ha	Liquid L/ha	Granules kg/ha
Barley, wheat	3.0	11.0	3.5	14.0	4.2	17.0
Canola, flax, mustard, sugar beets	3.5	14.0	4.2	17.0	5.5	22.0

* Anonymous. 1987.

† Avadex BW contains triallate 400 g/L in liquid formulation and 10% by weight in granular formulation.

TABLE 10. EFFECT OF SOIL pH ON ADSORPTION OF SELECTED HERBIDICES*

Herbicide		Adsorption
Trade name	pH designation	strongest at
	IONIC	
Roundup	Strongly Acidic	Low Soil pH
2,4-D	Weakly Acidic	Low soil pH
Banvel	Weakly Acidic	Low soil pH
MCPA	Weakly Acidic	Low soil pH
Tordon	Weakly Acidic	Low soil pH
Aatrex, Primatol	Weakly Basic	Low soil pH
Bladex	Weakly Basic	Low soil pH
Lexone, Sencor	Weakly Basic	Low soil pH
Princep, Simmaprim	Weakly Basic	Low soil pH
Gramoxone, Sweep	Strongly Basic	Neutral to high soil pH
Reglone	Strongly Basic	Neutral to high soil pH
	NONIONIC	
Avadex BW	Nonionic	No significant effect
Karmex	Nonionic	No significant effect
Treflan, Rival	Nonionic	No significant effect

*After Paulson, Jr., D. 1981.

Soil moisture and temperature

These are the most critical factors in determining the persistence and carry-over of herbicides in soil. Both factors affect herbicide leaching, evaporation, adsorption and degradation by chemical and biological processes.

The rate of physical removal of herbicides because of leaching, evaporation and adsorption is higher in moist warm soils than in dry cold ones. Thus dry and cool soils will have greater potential for herbicide carry-over into the next year.

Microbial breakdown of herbicides is favored by a soil temperature of 15°C and higher, and soil moisture levels near field capacity. Thus, in winter, when the ground is frozen, there is no herbicide loss caused by soil microbes. Similarly when the soil is dry, as it can be during some summers, there will only be a slow breakdown of herbicides, increasing potential for carry-over.

WEATHER-RELATED FACTORS

Temperature and rainfall are the major weather-related factors directly influencing the potential for herbicide carry-over. Lower temperatures (less than 15°C) decrease evaporation and microbiological and chemical breakdown of herbicides. Lower temperatures therefore increase the potential for herbicide carry-over into the following year.
Rainfall influences herbicide persistence directly by physically leaching herbicides through the soil profile. For instance, rainfall during the growing season decreases the potential for carry-over of water-soluble herbicides.

Figure 5 illustrates the influence of total rainfall during the year on herbicide carry-over in prairie soils. It presents the results of a study carried out in Regina on heavy clay soil over a 10-year period. Avadex BW and Treflan were applied at recommended rates in the spring of year one and the soils were sampled the following May to determine carry-over. It was observed that carry-over within a given year was closely related to the annual rainfall. From 1972 to 1978, when the annual rainfall was close to the 30-year average of 40 cm, the herbicide carry-over was between 10-20 per cent of the amount applied. A greater carry-over of the two herbicides was found following application in 1979 and 1980. Rainfall in 1979 was below average, which explains the increased carry-over. In 1980, there was more rain but most of it was later in the season. The spring was dry and most of the liquid herbicide was quickly adsorbed to the dry soil during application and incorporation. The late rainfall did very little to reduce the carry-over.

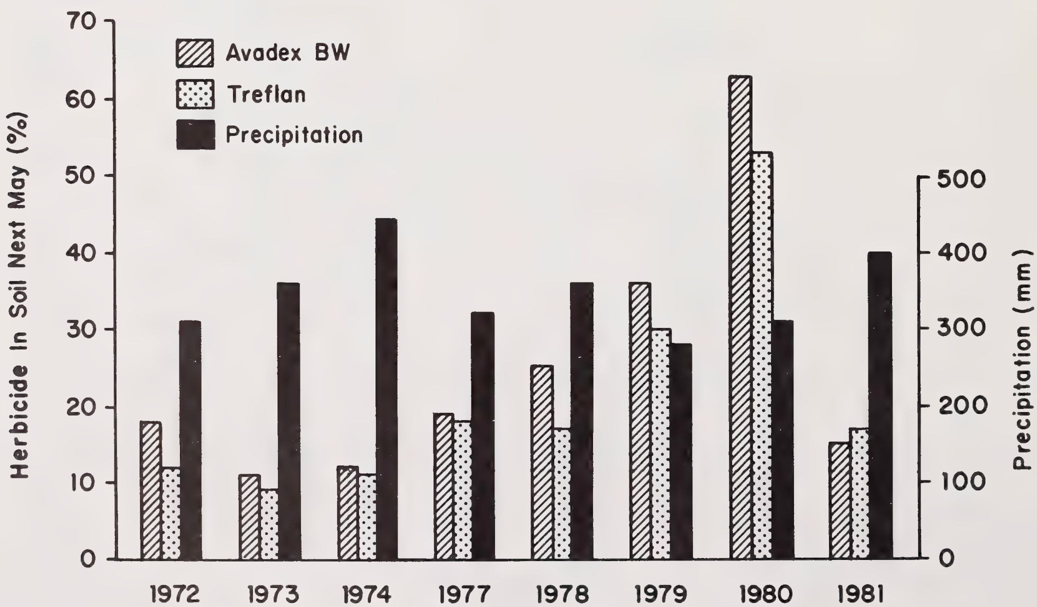

Figure 5. Influence of rainfall on carry-over to the following year of liquid Avadex BW and Treflan (Data from Smith, A.E. 1982b).

OTHER FACTORS

Minimum tillage

Minimum tillage can affect the potential for herbicide carry-over. Minimum-tillage fields often require a higher herbicide rate to achieve an acceptable level of weed control since cultivation is reduced. At harvest, crop residue left on the soil surface may increase the concentration of herbicide residues at this soil surface.

Crop/plant uptake

Plants absorb herbicides from the soil solution and reduce the concentration of herbicides in the soil. For example, if Aatrex is applied at the same rate in a field with light and heavy quack grass infestations, the amount of herbicide left in soil will be greater in the light infestation areas, thus creating "hot spots".

Use of fertilizers

Plant growth and herbicide decomposition by microorganisms are influenced by soil fertility. Fertilizers increase mineral nutrients in the soil and enhance crop growth and the proliferation of soil microorganisms, which may in turn increase microbial breakdown of the applied herbicide. If the soil is poor in nutrients, growth of soil microorganisms and the breakdown of herbicides may be slowed, thus increasing the potential for herbicide carry-over.

Can herbicide carry-over be avoided?

"Prevention is better than cure". This saying has merit when applied to herbicides. However, the benefits of some of those excellent herbicides which have residual properties, and which are required to handle certain weed problems must not be lost. It is important to plan a weed control strategy carefully so that herbicide carry-over can be avoided.

Planning should be based on all available information on weed problems, herbicides, soil characteristics and weather conditions. Also consider that this plan will have a bearing on the following year or two. Therefore, plan to maintain records on products used, weather, and land preparation. Make note of any other pertinent information which may help in making decisions in the following years to avoid crop losses caused by herbicide carry-over. A weed control plan with little or no herbicide carry-over may be based on:

1. **Alternate weed control measures** — Use cultural practices such as different tillage methods, seeding times, selection of crops, and use fertilizers designed to avoid weed-crop competition and/or to give some growth advantage to the crop over weeds.
2. **Integrated weed management** — Use cultural measures together with herbicides to minimize carry-over the following year.
3. **Herbicide rotation with crop rotation** — This is an important consideration. Proper rotation can avoid carry-over and/or accumulation of herbicides in the soil. For example, canola treated with Treflan could be rotated with cereals on which a foliar-applied herbicide, such as Hoe-Grass, is used for wild oat control.
4. **Herbicide with a minimum carry-over**— Consider information provided in Table 11, on average carry-over in prairie soils, for the selection of an appropriate herbicide to fit a weed control and crop rotation plan compatible with the local soil and weather conditions. Select a herbicide with few residual properties and minimum carry-over.
5. **Minimum rates of herbicides** — Rate of application of some herbicides should be selected on the basis of soil type, soil moisture content, level of weed infestation and anticipated weather conditions during the growing season. Theoretically, the rate of a herbicide should never be more than the minimum amount required to achieve an acceptable level of weed control. This practice will reduce the potential for herbicide carry-over. For example, on a light soil with low moisture a lower rate of Treflan will reduce the potential for carry-over (see Table 6).

Table 11. AVERAGE CARRY-OVER OF SELECTED HERBICIDES IN PRAIRIE SOILS*

Percent of amount applied	Herbicides
0	Asulox, Banvel, Bladex, Buctril M, phenoxies†, Poast, Stampede
5 - 10	Eptam, Hoe-Grass, Lexone L, Sencor
10 - 20	Avadex BW (E.C.), Aatrex, Mataven, Treflan (E.C.)
20 - 30	Avadex BW (Gran.), Glean, Lorox L, Princep, Tordon, Treflan (Gran.)

* Smith, A.E. 1985.
† such as 2,4-D, MCPA

6. **Type of formulation** — Avoid using herbicide formulations designed to release the herbicide slowly over a long period of time, such as granular formulations of Treflan or Avadex BW. Table 9 provides information on recommended rates of Avadex BW liquid and granular formulations.

7. **Herbicide mixtures** — Use a residual herbicide at a reduced rate in a tank-mix with a non-residual herbicide (Table 12). Check information on the product label for exact rates and application instructions. It is important to remember that the use of an unregistered mix is illegal and will void any guarantee of efficacy offered by the manufacturers.

8. **Time of application** — Early spring application of some herbicides, such as Treflan, is recommended for reducing the potential for carry-over. However, applications are often delayed because of unfavorable weather. Plan ahead and complete application as early as possible.

9. **Proper application** — Care in application of a herbicide is essential. To avoid unnecessary herbicide carry-over, read the label before using a product, follow all the instructions and precautions, mix the right amount of active ingredient, calibrate the sprayer, avoid overlapping spray runs and overdosing at corners, avoid wet lands, and incorporate properly. Careful and proper application of a herbicide will reduce its potential for carry-over.

How to recognize herbicide carry-over

A carefully kept record of the products used last year, and of the weather conditions since the application, will help determine whether there may be carry-over in a field. For example, there may be more than expected carry-over of Treflan or Avadex BW in fields if the herbicides were applied on very dry soils in the spring and if it rained only in the later part of the growing season. Consider another situation. Suppose it has been four years since Tordon 202C was applied for control of hard-to-kill weeds in wheat. Now you plan to seed alfalfa or a specialty crop such as lentils. How can you be sure that there are no residues in the soil or that the level of residues is low enough not to hurt the crop? The findings may change your plan of seeding alfalfa or lentils.

There are three methods for determining the level of herbicide residues in a soil:

- instrumental or chemical analysis
- indoor (greenhouse) bioassay
- field bioassay.

Instrumental or chemical analysis

Instrumental or chemical analysis can determine the concentration of herbicide in a soil sample. The process, which is very accurate but slow and expensive,

can only be carried out in specialized laboratories. It is important to remember that the accuracy of the findings is dependent upon sampling technique and efficiency.

The presence of a residue in a soil sample is often reported in terms of parts per million (ppm) on a weight by weight basis. In other words, there is a measured weight of herbicide residue in micrograms (μg) per gram of soil [one ppm is equivalent to one microgram per gram ($\mu g/g$)]. What does it mean in practical terms? Table 13 shows the relationship between the herbicide residue concentration (ppm) in the soil sample and the approximate amount of herbicide residue present in the field, where the residue-containing layer is 4, 8 and 16 cm thick and when the soil bulk density is assumed to be 1.2 g/cm^3.

Indoor (greenhouse) bioassay

A biological assay or bioassay consists of growing plants of certain sensitive crops, including the one to be planted, in soil samples collected from the field suspected of containing herbicide carry-over (Fig. 6). If injury occurs to these test plants, then the potential exists for crop injury in the field. The accuracy of the test depends upon the sampling technique. For a better indication of possible carry-over, soil samples should be taken and the test conducted just before seeding time. Make sure that results are available prior to making a decision on rotation.

To obtain a uniform sample of the soil, randomly collect soil from all areas of the field. Soil samples should be collected from 0-8 and 8-16 cm deep, keeping the soil from the two testing depths separate. Each test requires about four litres of soil. Field ends and knolls, areas which frequently have higher residues, may need to be tested separately.

An untreated (check) soil sample should be gathered at the same time to be used for comparison of seedling growth. Obtain the check sample from a similar soil that has not been treated with the herbicide.

Either run the test within a week or two of taking the soil sample, or store the soil under cold conditions (outside in winter or in a freezer). If the soil is wet, spread it out in a thin layer to dry. Crush clods to pea-sized particles. Do not pulverize. If the soil sample is high in clay, add some sand. Do not add peat moss, sandy soil or vermiculite.

Three to four pots of each treated soil and check soil should be made so that variability in plant growth will not cause wrong conclusions to be made. Half-litre or one-litre pots may be used to grow the plants. Make sure there are no drainage holes in the bottom of the pots, otherwise the residues of some herbicides may be leached away with the water.

Select plant species sensitive to the suspected residue (Table 14). Plant 10-15 viable seeds approximately 1 cm deep in each container. Wet the soil but do not saturate it. Seed only one plant species per pot and label the pot.

Place the container in a warm, bright part of the house, preferably near a south-facing window. Adequate sunlight and warm conditions (approximately 21°C) are essential for residue injury symptoms to develop. Allow plants to grow to at least the four-leaf stage of development. Water the containers as often as necessary but do not overwater. Once the seeds have germinated, thin the stand to 5-10 plants per pot. Injury symptoms usually appear within 10-20 days after emergence. However, if room temperature is below 21°C, it may take longer.

A bioassay conducted indoors may not be reliable for certain herbicides such as Glean or Tordon 202C. These herbicides can be present at such low levels that accurate sampling is difficult. It is therefore necessary to set up a field bioassay.

D. Lobay

Figure 6. Indoor bioassay for detecting Hyvar-X residues. Plants in the back row are controls. Plants in the front row are grown in soil with some carry-over.

TABLE 12. SOME HERBICIDE TANK-MIXES REGISTERED FOR USE IN ALBERTA*

Residual herbicide	Mix with
Afolan F	MCPA amine
Atrazine F	Buctril M, Bladex
Banvel 400	MCPA amine, MCPA-K, 2,4-D amine, 2,4-D ester
Banvel 480	Lexone DF, Sencor
DyCleer	2,4-D amine, 2,4-D LV ester, 2,4-D + dichlorprop
Lexone	MCPA amine, Banvel, Eptam
Lorox L	MCPA amine
Primatol	2,4-D amine, 2,4-D ester, Gramoxone
Sencor	MCPA amine, 2,4-D amine, Target, Banvel, Eptam
Glean	Roundup, Avenge 200-C, Hoe-Grass 284, Stampede 360, Mataven

*Information from Stearman, W.A. 1986.

TABLE 13. RELATIONSHIP BETWEEN HERBICIDE RESIDUE CONCENTRATION (PPM) IN THE SOIL SAMPLE AND APPROXIMATE AMOUNT OF HERBICIDE RESIDUES (kg/ha) IN THE FIELD*

Herbicide residue equivalents per soil layer								
Top 4 cm			Top 8 cm			Top 16 cm		
PPM		kg/ha	PPM		kg/ha	PPM		kg/ha
0.5	=	0.3	0.5	=	0.6	0.5	=	1.2
1.0	=	0.6	1.0	=	1.2	1.0	=	2.4
2.0	=	1.2	2.0	=	2.4	2.0	=	4.8
3.0	=	1.8	3.0	=	3.6	3.0	=	7.2
4.0	=	2.4	4.0	=	4.8	4.0	=	9.6
5.0	=	3.0	5.0	=	6.0	5.0	=	12.0
6.0	=	3.6	6.0	=	7.2	6.0	=	14.4
7.0	=	4.2	7.0	=	8.4	7.0	=	16.8
8.0	=	4.8	8.0	=	9.6	8.0	=	19.2
9.0	=	5.4	9.0	=	10.8	9.0	=	21.6

*After Anonymous. 1979.

TABLE 14. SELECTION OF PLANT SPECIES FOR HERBICIDE BIOASSAY

HERBICIDES \ SENSITIVE PLANTS	Alfalfa	Faba Bean	Barley	Beet	Corn	Cucumber	Green Foxtail	Lettuce	Mustard/Canola	Oat	Pumpkin	Rye Grass	Sedge	Sunflower	Wheat	Wild Oat	Watermelon	Sugar Beet	Tomato	Wild Mustard	Lentils
Aatrex	S	S	S	VS	T	VS	S	S	S	VS	S				S	MS		S	S	S	
Hyvar-X	S	S	S	S	S	S	S	S	S	S	S			S	S	S	S	S	S	S	S
Basfapon			T			S	S		T	T					S	T					
Banvel	S	S	T	VS	MT	S	T	S	MT	S	S			S	T	T			VS		S
Karmex	S	S	S	S	S	S				S	S	S							S	S	S
Eptam	T	T	S	MS	T	S	S	S	T	S	S			T	S	S		T	MS		T
Afolen F, Lorox L	MT	S		MS	MS	S	MS	MS			S	S						S	MT	S	
Sencor, Lexone	MT	S	MT	S	MS	S	MT	S	VS	MT	S			S	MT	MT	VS	VS	T	VS	MT
Tordon	S	VS	MT	S	MT	S		MT	T	T	S			VS	MT	MT	S	S	VS	T	VS
Simmaprim	S	S		S	T	S		S	S	S	S	S						S	MS		
Avadex BW	MT	T	T	MS	MT	S	T	MS	T	S	S	MS	S		T	VS		T	MT	T	T
Treflan, Rival	T	T	T	S	MS	MS	VS	T	T	VS	S	S		T	MS	VS			T	T	T
2,4-D, MCPA	S	S	T		T	S	T	S	S	T	S			S	T	T		S		S	T
Glean	VS	S	T	VS	S	S		S	S	T	S			S	T	T		VS	S	S	VS
Lontrel	S	S	T	T	T	S		T	T	T	S			S	T	T		T	T	T	VS

VS = very susceptible S = susceptible MS = moderately susceptible MT = moderately tolerant T = tolerant

Field bioassay

A field bioassay involves growing a test strip of the crop one plans to grow the following year, in fields previously treated with persistent herbicides such as Glean or Tordon 202C. Crop response will indicate whether or not to rotate to the tested crop. Here is the method recommended by DuPont Canada Inc. for Glean:

1. Select a representative area of the field previously treated with Glean to plant the bioassay crop. Be sure to consider factors such as size of field, soil texture, drainage, turn – around areas, eroded knolls or alkaline spots when selecting the site that is most representative of the soil conditions in the field. On large fields, more than one bioassay site may be needed to obtain reliable results.
2. Plant the test strip at right angles to the direction in which the field was sprayed. The strip should be long enough to cross several spray swaths. A large test area is more reliable than a small one. Suggested size is 0.1 – 0.25 hectare (approximately 0.25 – 0.6 acres) per site.
3. Use standard tillage and seeding equipment to plant the bioassay area.
4. Prepare a seedbed and plant the crop and variety you want to grow the following year. It is important to use the same planting time, conditions, techniques and cultural practices you normally use to plant and grow the bioassay crop. If possible, plant into an adjacent area not treated with Glean for a comparison.
5. To avoid damage to the bioassay crop do not overspray the test strip with herbicides.
6. If the crop in the test area grows to maturity with a normal yield, the assay indicates that you may now rotate to the new crop. However, if the plants in the test strip die, are stunted, or fail to yield normally, the assay results show that you should not rotate to the new crop. Before rotating to a new crop repeat the assay until results show that there are no harmful residues left.
7. If the bioassay indicates that Glean residues are still present, continue cropping wheat or barley or fallow the field. Do not rotate to crops other than wheat or barley until bioassay results indicate that susceptible crops are growing normally.

How to remedy herbicide carry-over

Once the presence of herbicide carry-over in the soil is established (as in Fig. 7), action must be taken to reduce damaging effects from residues and to reclaim the soil. Plan like a doctor to cure the soil condition. Know the problem and the factors which contributed to it. Review all the available remedies to put together a prescription. It could be a stimulating challenge to test your knowledge, skills and experience.

One needs to adopt measures which assist in eliminating residues from the contaminated soil, by binding residues to soil particles, and degrading the active molecules into nontoxic and harmless products. These measures should be economically acceptable and not cause secondary effects which may be worse than the herbicide carry-over problem.

D. Lobay

Figure 7. Wheat crop damage caused by Treflan carry-over resulting from misapplication.

How to manage herbicide carry-over

CROP-RELATED MANAGEMENT

Tolerant crops

Crops tolerant to the carried-over herbicide may be planted in the field. The residue, taken up by tolerant plants, is either stored or broken down into nontoxic compounds. Carefully select a crop tolerant to the herbicide residue. A summary of information on some products used in Alberta is presented in Table 15. However, for specific information read the label of the product used and make a note of recropping restrictions, the crop(s) which can be seeded in rotation and the length of time (waiting period) after which a sensitive crop can be planted.

Some crop cultivars also vary in their tolerance to specific herbicides and this should be considered when selecting a crop in the rotation. Also, crop cultivars are being bred for tolerance to specific herbicides. An example is a triazine-tolerant canola cultivar now registered as Triton.

Seeding

Proper selection of seed, seeding date and depth of seeding can help prevent crop injury from herbicide residues. Large-seeded cultivars produce vigorous seedlings which may tolerate a certain level of herbicide residues.

Time of seeding may be helpful in avoiding crop injury. For instance, early seeding in a cool dry spring may reduce injury to crop seedlings. In another situation a delay in seeding can minimize the risk of crop injury by allowing more time for herbicide residues to break down.

Seeding depth could be critical in a field containing herbicide residues which are taken up by the shoot. For example, deep seeding in a field with Treflan carry-over will increase the risk of crop injury, therefore shallow seeding of a cereal crop is recommended.

Crop safeners

Treating seeds with activated charcoal has been used to avoid or reduce injury to emerging seedlings from herbicides in soil. However, this treatment often does not provide sufficient protection to the developing seedlings.

New chemical agents or crop safeners have been developed for use as seed treatments to protect seedlings from herbicides. For example, naphthalic anhydride (NA) is used for seed treatment to protect corn from Eptam and other thiocarbamate herbicides. Cyometrinil and flurazole are recommended to protect sorghum from Dual and Lasso. These chemicals, taken up by the seedlings of treated seeds, compete for sites sensitive to herbicides.

Herbicide rotation

Accumulation of residues in the soil can be avoided by not using the same herbicide year after year. For example, to avoid Treflan build-up, Hoe-Grass could be applied to a second-year crop of canola in a field previously treated with Treflan.

While making decisions about herbicide rotation, avoid unwanted interaction between the carried-over herbicide and the rotation herbicide. For instance, a soybean crop that may tolerate a certain level of Aatrex carry-over, may be injured if another photosynthesis-inhibiting herbicide such as Sencor is applied to the crop.

SOIL-RELATED MANAGEMENT

Land preparation

Ploughing and tilling may be needed to dilute the effect of carry-over. Tilling will enhance residue dissipation by stimulating adsorption and microbial breakdown. Ploughing will bury the contaminated soil surface layer. It will also incorporate plant residues, loosen and aerate soil and increase water infiltration, thus enhancing adsorption, leaching, and microbiological breakdown of herbicide residues. For instance, Treflan residues in the soil surface layer can be made nontoxic to a susceptible surface-seeded crop by plowing the soil before planting. This is because Treflan is taken up by the emerging shoots rather than the roots. Therefore by ploughing under Treflan residues, the herbicide's toxicity to a surface-planted crop is reduced.

TABLE 15. RECROPPING RESTRICTIONS*

Herbicide	Crops which may be affected the year following use of the herbicide
atrazine (includes all products containing atrazine)	All crops except corn and triazine-tolerant canola. Peas, flax and faba beans have some tolerance to atrazine residues. If rate of application exceeds 0.45 kg/ha, only corn or triazine-tolerant canola should be grown the following year. Atrazine residues may persist for more than one year.
Avadex BW	Oats
Bladex	All crops except corn, triazine-tolerant canola, cereals, potatoes, canola, sunflowers, soybeans and peas. There is no recropping restriction at the rates recommended for use in triazine-tolerant canola.
Glean	All crops except wheat or barley. On soils with a pH of 7.5 or less, only wheat may be seeded the following year. If the soil pH is 7.0 or less either wheat or barley may be seeded the year following the Glean application. These restrictions severely limit cropping opportunities on Glean-treated fields.
Lontrel	Legumes including beans of all types, peas, lentils; forage legumes such as alfalfa, clover; sunflowers and safflowers; and solanaceous (Potato family) crops such as potatoes, tomatoes, and tobacco. Allow one clear year after the year of treatment before planting these crops in land previously treated with Lontrel. Fields treated in the previous year with Lontrel should not be planted to sensitive crops, but can be seeded to barley, flax, oats, canary seed, mustard, canola, rye, wheat, corn, forage grasses or sugarbeets.
Princep Nine-T, Simadex	All crops except established forage legumes where recommended. Residues may persist for 2 or more years.
Sencor, Lexone (preplant recommendations)	Canola, sunflowers, sugar beets, onions, celery, peppers, cole crops, lettuce, spinach, red beets, turnips, pumpkins, squashes, cucumbers and melons. Fall-seeded crops may also be injured when seeded within the same season as the application of Sencor or Lexone.
Sinbar	All crops except established alfalfa as recommended. Sinbar residues may persist for 2 or more years.
Tordon 202C	Replant to wheat, barley, oats, flax or canola for 2 years following treatment. Do not plant fields treated with Tordon 202C to alfalfa or sunflowers until at least the third growing season after the year of treatment, or beans, lentils, peas or potatoes until at least the fifth growing season after the year of treatment. Because of the length of the recropping restriction Tordon 202C is not recommended on farms where vegetable crops, pulse crops or forage legumes are included in the crop rotation.
Treflan	Sugar beets, red beets, oats, fall rye, canary seed or small-seeded grasses. Corn may also be sensitive to higher rates of application.

*Anonymous. 1985.

Soil additives

Use of fertilizers — The use of fertilizers will encourage vigorous growth of tolerant plants, resulting in substantial uptake of the herbicide in soil. It will also enhance the growth of microflora, increasing biological breakdown of herbicide in the soil. For instance, addition of phosphorus fertilizers enhances microbial breakdown of 2,4-D and MCPA.

Use of adsorbents — Most herbicides are adsorbed to soil particles such as clay and organic matter. Adsorption of herbicide carry-over could be increased by the addition of adsorbent material such as activated charcoal.

1. Activated charcoal — This is ordinary charcoal which has been finely ground to increase its adsorptive surfaces, and has been electrically charged so it will attract oppositely charged herbicide molecules or ions. The charcoal can be applied to the soil dry or as a slurry in water and thoroughly incorporated to a depth of 8-16 cm into the soil. It can also be applied as a seed treatment or as a root dip.

The efficiency of activated charcoal depends on the characteristics and physical conditions of the soil, and the type and amount of herbicide in the soil. For example, less activated charcoal is required for inactivating some herbicides such as Aatrex. Treflan and Princep in soil containing high rather than low amounts of organic matter. It has also been established that higher amounts of activated charcoal will be needed to inactivate increasing levels of a herbicide in the same type of soil (Fig. 8).

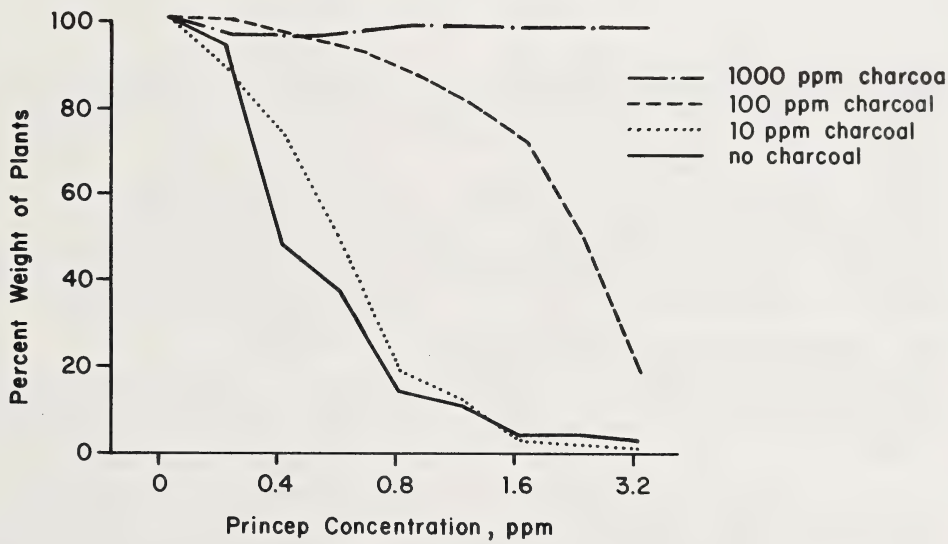

Figure 8. Effects of activated charcoal (Norite A) as a soil amendment on the fresh weight of seedling oats growing in soil containing Princep (Sheet, T.J. and C.I. Harris, 1965).

Table 16 contains information on the approximate amounts of activated charcoal required to inactivate most of the commonly used herbicides. More charcoal may be required to inactivate specific amounts of some herbicides in the same or different types of soils. For instance, it has been demonstrated that 100 and 400 kg of activated charcoal are required to inactivate 1 kg of Princep and Banvel, respectively, in one hectare of contaminated land.

The use of activated charcoal on a large scale is not economic. However, on a limited acreage of high production potential or high-value crops, or as spot treatments, its use might be acceptable and profitable. Activated charcoal is most suitable for specialized uses such as root dipping or localized application to clean up herbicide spills.

TABLE 16. APPROXIMATE AMOUNT OF ACTIVATED CHARCOAL REQUIRED TO INACTIVATE SOME HERBICIDES IN SOIL*

Active ingredient in soil		Charcoal required
kg/ha	g/100m²	kg/100m²
0.1	1	0.1 - 0.2
0.2	2	0.2 - 0.4
0.4	4	0.4 - 0.8
0.5	5	0.5 - 1.0
1.0	10	1.0 - 2.0
1.5	15	1.5 - 3.0
2.0	20	2.0 - 4.0
3.0	30	3.0 - 6.0
4.0	40	4.0 - 8.0
5.0	50	5.0 - 10.0

*Information from Mitich, L.W. 1980.

2. Organic matter — Most herbicides are adsorbed by the soil organic matter. Therefore an addition of organic matter into the soil will assist in inactivating herbicide residues. Usually farm manure is used for this purpose. However, ploughing under a green manure crop, sewage waste, or composted garbage not only will increase herbicide adsorption but will also stimulate the growth of microorganisms in the soil, thus aiding in herbicide breakdown.

   Crop production practices which provide a continuous source of organic matter to the soil will tend to increase adsorption and microbial activity which in turn help to decompose herbicide residues.

3. Use of microbial additives — Specific microorganisms which break down certain herbicides have been isolated from soil. Application of such microbial cultures could eliminate herbicide residues. For example a microbe *(Pseudomonas cepacia* strain ACIOO) has been shown to break down Easteron (2,4,5-T). Research in this area is being carried out to develop economically acceptable and problem-free soil microbial additives which could be used to degrade various herbicides in soil.

Soil pH

Soil pH influences microbial growth and activities, adsorptive characteristics of soil and chemical breakdown of herbicides in soil. Laboratory and small-scale field studies suggest that the activity of herbicides in the soil can be reduced by altering soil pH. The use of lime, fertilizers, and acid-forming agents such as sulfur or gypsum can change soil pH and assist in inactivating herbicide residues. For example, Aatrex phytotoxicity is reduced as soil pH is decreased with the use of ammonium nitrate fertilizer. It is not known whether it is economically feasible to reduce activity of herbicides such as Glean by changing soil pH under field conditions.

Irrigation

Irrigation increases soil moisture which will enhance inactivation or breakdown of herbicide residues. This is because the increased soil moisture will increase the efficiency of physical processes and microbiological activities in the soil. For example, an increase in soil moisture will increase the leaching of Treflan and the evaporation of Aatrex. Irrigation soon after seeding can also assist in temporarily moving residues out of a seed bed to avoid injury to emerging seedlings.

Summerfallow

If a field is heavily contaminated and other measures do not seem to be working, the field may be taken out of production and fallowed. Regular cultivation and tillage during the fallow period will enhance dissipation and degradation of herbicide residues by creating favorable conditions. Regular turning and mixing of soil will enhance adsorption, breakdown by sunlight, and evaporation, and the well-aerated soil will increase microbial breakdown of herbicide residues.

Summary

- Herbicide persistence is desirable when extended weed control is required.
- Herbicide persistence is a problem when carry-over affects crops grown in subsequent years.
- Herbicide-related factors such as type of herbicide, its water solubility, adsorption, volatility, decomposition by sunlight, chemical breakdown, microbial breakdown, rate of application, formulation and time of application affect the rate of removal and inactivation.
- Soil-related factors which influence herbicide persistence are texture, organic matter, pH, moisture, temperature and fertility.
- Temperature and rainfall before, during and after the growing season influence the rate of breakdown.
- Herbicide carry-over can be avoided by using herbicides which have low or no carry-over potential, alternate methods of weed control, uniform application techniques and careful planning of crop and herbicide rotations.
- Injurious levels of herbicide residues can be identified by instrumental analysis, indoor (greenhouse) or window bioassay and field bioassay. Different techniques are required for different herbicides.
- Planting tolerant crops, proper land preparation, use of fertilizers and irrigation, suitable seed treatment and seeding techniques, and the use of soil amendments, including activated charcoal and manure, are methods of managing herbicide residues.

References consulted

Anderson, W.P. 1983. Weed Science: Principles. Second Edition. West Publishing Company, New York, NY. 655 pp.

Anonymous. 1979. Herbicide Dosages and PPM. Plant Industry Division/Alberta Agriculture News 5(3):8.

Anonymous. 1981. Treflan* E.C. Elanco. Division Eli Lilly Canada Inc., Scarborough. 4 pp.

Anonymous. 1983. Herbicide Handbook of the Weed Science Society of America. Fifth Edition. Weed Science Society of America, Champaign, IL. 515 pp.

Anonymous. 1984. Field Bioassay - Glean. DuPont Canada Inc., Mississauga. 2 pp.

Anonymous. 1985. Guide to Chemical Weed Control. Agdex 641. Manitoba Agriculture, Winnipeg. 120 pp.

Anonymous. 1987. Guide to Crop Protection in Alberta 1987. Part I Chemical. Agdex 606-1. Alberta Agriculture, Edmonton. 165 pp.

Burnside, O.C. 1974. Prevention and Detoxification of Pesticide Residues in Soils. In Pesticides in Soil and Water. W.D. Guenzi, ed. Soil Science Society of America, Madison, WI. pp 387-412.

Coffey, D.L. and G.F. Warren. 1969. Inactivation of Herbicides by Activated Carbon and other Adsorbents. Weed Sci. 17:16-19.

Furer, J.D. and A.R. Martin. 1981. Herbicide Residues and 1981 Plantings. Nebraska Weed Science Newsletter X(1):2.

Gray, R.A., L.L. Green, P.E. Hoch and F.M. Pallos. 1982. The Evolution of Practical Crop Safeners. Proc. 1982 Brit. Crop Protection Conf. - Weeds 2:431-450.

Grover R. and A. E. Smith. 1974 Herbicide Behaviour in the Environment. Canadex Weed Control 641. Agriculture Canada, Ottawa. 2 pp.

Harvey, R.G. 1973. Influence of Cropping and Activated Carbon on Persistence of Atrazine in Sand. Weed Sci. 21:204-206.

Holm, R. 1985. Herbicide Residue "Hangover" can be Avoided. Farm Light & Power. December/January, 1984/85. 14 pp.

Hurle, K. and A. Walker 1980. Persistence and Prediction. In Interactions Between Herbicides and the Soil. R.J. Hance, ed. Academic Press, Toronto. pp 83-122.

Ivany, J.A., J.M. Sadler, E.R. Kimball, and K.B. McRae. 1984. Atrazine Persistence and Residue Effects on Rotation Crop. Can. J. Plant Sci. 65:363-368.

Klingman, G.C. and F.M. Ashton. 1982. Weed Science: Principles and Practices. Second Edition. John Wiley & Sons, New York, NY. 449 pp.

Martin, A.R., O.C. Burnside, P.A. Shea, G.A. Wicks, R.S. Moomaw, R.G. Wilson, F.W. Roeth, and J.D. Furrer. 1983. Herbicide Carryover. NebGuide G83-637. Cooperative Extension Service, Institute of Agriculture and Natural Resources, University of Nebraska, Lincoln, NE. 4 pp.

McGregor, W. 1985. The Degradation of Pesticides in Soil. Alberta Environment. Pesticides In Focus 3(1):1-9.

Mitich, L.W. 1980. Deactivating Herbicides with Activated Charcoal. North Dakota Pest Report 11:1-2.

Morrison, I.N., A.E. Smith and D.A. Pehajek. 1982. Herbicide Residues in Soil. Weed Reference Bulletin. Manitoba Agriculture, Winnipeg. 3 pp.

Paulson, Jr., D. 1981. Effect of pH, Organic Matter and Soil Texture on Herbicides. Solutions Magazine. January/February Issue: 10-15.

Roberts, H.A. 1982. Weed Control Handbook: Principles. Seventh Edition. Blackwell Scientific Publication, London, U.K. 533 pp.

Ross, M.A. and C.A. Lembi. 1985. Applied Weed Science. Burgess Publishing Company, Minneapolis, MN. 340 p.

Shea, P.A. 1985. Detoxification of Herbicide Residues in Soil. Weed Sci. 33 (Suppl. 2):33-41.

Sheet, T.J. and C.I. Harris. 1965. Herbicide Residues in Soils and Their Phytotoxicities to Crops Grown in Rotation. Residue Rev. 11:119-140.

Smith, A.E. and B.J. Hayden. 1980. The Persistence of Commonly Used Herbicides in Prairie Soils. Canadex. Weed Control 641. Agriculture Canada, Ottawa. 2 pp.

Smith, A.E. 1982a. Herbicides and the Soil Environment in Canada. Can. J. Soil Sci. 62:433-460.

Smith, A.E. 1982b. Carry-over of Avadex-BW and Treflan in the Soil. Agriculture Canada Research Station, Regina. Research Highlights 22-23.

Smith, A.E. 1985. The Influence of Environmental Factors on the Soil Persistence of Herbicides. Manitoba Agriculture. Weed Fair Handbook 10-13.

Stearman, W.A. 1986. Herbicide Tank Mixes. Agdex 606-10. Alberta Agriculture, Edmonton. 2 pp.

Upchurch, R.P. 1966. Behaviour of Herbicides in Soil. Residue Rev. 16:46-85.

Van Der Ruy, D. 1984. Herbicide Persistence in Soils. North Dakota Pest Report 15:1-2.